NON-PERTURBATIVE EFFECTS IN e^+e^- EVENT-SHAPE VARIABLES

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Abstract

We review theoretical methods employed to study non-perturbative contributions to e^+e^- event-shapes and discuss their phenomenological relevance.

1 Introduction

Event-shape variables in e^+e^- annihilation, such as Thrust T, Heavy-jet Mass M_H, C-parameter, Broadening B, have provided various tests of QCD and a way to measure α_s. Besides the perturbative (PT) results, agreement with data is achieved only by taking into account additional corrections of non-perturbative (NP) origin recently addressed through analytic approaches [1–3].

As explained in Section 2, the net effect of these corrections is to raise the mean value of an event-shape by an amount proportional to $1/Q$, being Q the center of mass energy. Similar features occur for distributions. In Section 3 *universality* of $1/Q$ corrections is discussed and it is mentioned how hadron mass effects partially spoil the 'simple' universality picture. We conclude in Section 4 giving some outlooks.

2 Power correction to event shapes

To see how NP corrections to event-shapes emerge, we consider, for instance, the mean value of $\tau \equiv 1-T$. As shown in fig. 1, a next-to-leading order (NLO) calculation alone does not fully describe data and one has to add a power suppressed contribution of the form C_τ/Q, with $C_\tau \simeq 1\text{GeV}$.

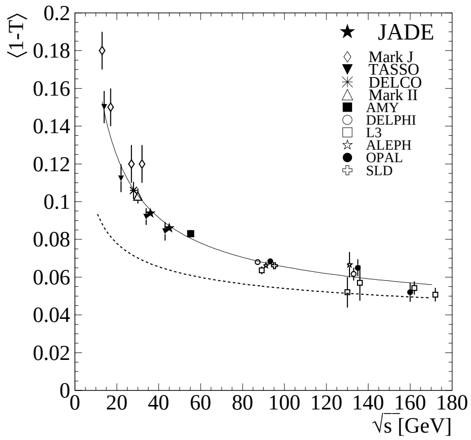

Figure 1: Mean value of $1-T$ as a function of Q [4]. The dotted line represents the NLO prediction, the solid line the improved prediction including a $1/Q$ correction.

One cannot get rid of this mismatch by simply taking into account higher orders in the PT expansion, since the PT series itself is divergent (for a recent review see [5]). Any attempt to give a meaning to the series leads to an ambiguity (infra-red renormalon) which, for event shapes, is of the order Λ_{QCD}/Q. This ambiguity must be canceled by a NP contribution with the same power behavior.

For the distribution the situation is more involved. Actually, the full τ distribution can be expressed as a convolution of a PT distribution with a NP shape function $f_{\rm NP}$. In the region $\tau \gg \Lambda_{QCD}/Q$ one can make the approximation

$$\frac{d\sigma}{\sigma d\tau} = \int d\epsilon f_{\rm NP}(\epsilon) \frac{d\sigma_{\rm PT}(\tau - \frac{\epsilon}{Q})}{\sigma d\tau} \simeq \frac{d\sigma_{\rm PT}(\tau - \frac{\langle\epsilon\rangle}{Q})}{\sigma d\tau}\,, \tag{1}$$

so that hadronization corrections result in a $1/Q$ power-suppressed shift of the PT distribution. In the region $\tau \sim \Lambda_{QCD}/Q$ higher powers become equally important, so that the full shape function should be kept. This is the basis of the Korchemsky-Sterman approach [3], where a parameterization of the shape function is given and the parameters are fitted to the data.

3 Universality of $1/Q$ power corrections

Although $1/Q$ power corrections are intrinsically NP quantities, one is able to predict their relative size from one observable to the next. First one observes that hadron multiplicity n_h is uniform in rapidity (η):

$$\frac{dn_h}{d\ln k_t d\eta} = \phi_h(k_t)\,, \tag{2}$$

with k_t the particle transverse momentum with respect to the thrust axis. This is the basis of the local parton hadron duality (LPHD) approach [6], where hadron momentum flow is supposed to follow parton flow. Furthermore, a soft particle contribution to an event shape may be written as the product of k_t/Q times an observable-dependent function of rapidity $f_V(\eta)$ (for the Thrust $f_\tau(\eta) = e^{-|\eta|}$).

As a consequence, the NP correction to the mean value of V can be expressed as (see for example [7], and references therein)

$$\langle V\rangle_{\rm NP} = \frac{\langle k_t\rangle_{\rm NP}}{Q} c_V\,, \quad \text{with} \quad \frac{\langle k_t\rangle_{\rm NP}}{Q} = \int \frac{dk_t}{k_t}\frac{k_t}{Q}\sum_h \phi_h(k_t)\,, \quad c_V = \int d\eta f_V(\eta)\,, \tag{3}$$

so that all the observable dependence is contained in the calculable coefficient c_V and one is left with only one unknown NP parameter $\langle k_t\rangle_{\rm NP}$. This property of $1/Q$ power corrections is commonly referred to as *universality*.

3.1 Dispersive method

A useful parameterization of $\langle k_t\rangle_{\rm NP}$ is provided by the dispersive approach [2], in which the running coupling is defined at any scale through a dispersion relation. The NP parameter $\langle k_t\rangle_{\rm NP}$ is related to α_0, the average of the dispersive coupling below a certain low scale μ_I (conventionally chosen to be $\mu_I = 2\,\text{GeV}$):

$$\frac{\langle k_t\rangle_{\rm NP}}{Q} = \frac{4C_F}{\pi^2}\mathcal{M}\frac{\mu_I}{Q}\alpha_0(\mu_I) + \mathcal{O}\left(\alpha_s(Q)\frac{\mu_I}{Q}\right)\,, \qquad \alpha_0(\mu_I) = \frac{1}{\mu_I}\int_0^{\mu_I} dk\,\alpha_s(k)\,. \tag{4}$$

Here the Milan factor $\mathcal{M}$ accounts for the non-inclusiveness of shape variables [7]. The value of α_0 has been measured by performing a simultaneous fit of α_s and α_0 to both mean values and distributions, and is found to be consistent with the universality hypothesis[1], as shown in fig. 2.

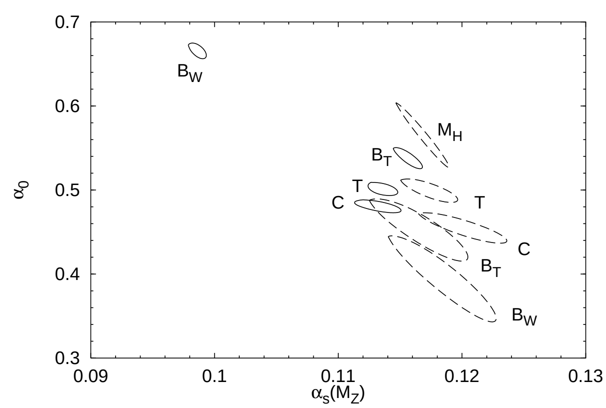

Figure 2: 2-σ contours for fits to various two-jet observables [8]. Solid curves indicate fits to distributions, while dashed lines indicate fits to mean values.

These fits have been performed only with two-jet event shapes. Only very recently these studies have been extended to three-jet events, and the power corrections to the thrust-minor and D-parameter have been addressed [9].

3.2 Mass effects and universality

Until now hadron masses have been neglected in the definition of the event-shapes. As shown in [10], hadron masses give rise to additional power corrections

[1]Actually, the $1/Q$ corrections to the wide-jet broadening B_W distribution are not yet believed to be fully understood. This seems to be a common problem of less inclusive quantities, such as B_W and M_H, where one particular hemisphere is chosen.

δV_m which, in general, are not proportional to c_V, thus spoiling the universality picture. However, with a suitable redefinition of the observables (E-scheme) one is able to eliminate the non-universal contributions leaving just universal mass corrections of the form

$$\delta V_m = c_V \frac{\mu_\ell}{Q} \ln^A \frac{\Lambda_{QCD}}{Q} \,, \qquad A = 4C_A/\beta_0 \simeq 1.6 \,, \tag{5}$$

with μ_ℓ a new unknown parameter which depends on the hadron level considered. Unfortunately, currently available data are not precise enough to extract α_0 and μ_ℓ simultaneously. However, changing the definition scheme or the hadron level results in systematic uncertainties in α_s and α_0 fits, thus revealing the presence of mass effects of the form predicted by eq. 5.

4 Conclusions

During this decade much theoretical and experimental effort has been devoted to the study of hadronization effects in e^+e^- event shapes. Experiments have confirmed the universality of $1/Q$ power corrections, thus supporting the validity of the LPHD approach. However, more refined analyses have revealed the need to include higher power corrections through a NP shape function and the existence of mass effects. These and related topics need further experimental investigation.

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